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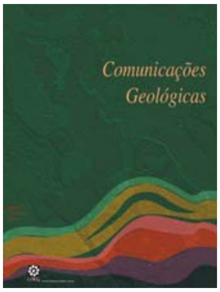
New data on the deposition age of the volcano-sedimentary Chela Group and its Eburnean basement: implications to post-Eburnean crustal evolution of the SW of Angola

Novos dados sobre a idade da sequência vulcano-sedimentar do Grupo Chela e do soco granítico subjacente: implicações na evolução crustal pós-Eburneana do SW de Angola



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Abstract: The Chela Group comprises a volcano-sedimentary sequence deposited in a widespread epicratonic basin that extends to southern of the Lubango region in SW of Angola. The basement rocks of the Chela Group integrate the Eburnean belt, consisting mainly of gneisses and migmatites, syntectonic foliated peraluminous granites, and late-tectonic metaluminous granites of the Chela and Gandarengos Mountains. Rb/Sr radiometric age of 2.1 ± 0.1 Ga was determined for the syntectonic granites whereas the late-tectonic Chela granite yielded a zircon U-Pb age of 1947 ± 5 Ma. This isotopic dating allow us to take it as a maximum age for the Chela Group. Moreover, the porphyritic calc-alkaline granite of the Gandarengos Mountain and a rhyolitic mass, spatially related to this granite, revealed U-Pb zircon ages of 1810 ± 11 Ma and 1814 ± 88 Ma, respectively. The rhyolite is intrusive into Tundavala Formation, base of the Chela Group, and should be the source of the pyroclastites composing the Humpata Formation. The time interval between 1814-1810 Ma obtained for the volcano-plutonism intrusive into the Chela Group restrains its minimum age and permits to define the interval 1947-1810 Ma as the main period of deposition of this sedimentary sequence in a post-orogenic environment.
After the deposition of the Chela Group, succeeds a period of crustal accretion marked by the installation of leucocratic peraluminous granites and an extensional Mesoproterozoic (1.4-1.1 Ga) bimodal magmatism, followed during the Neoproterozoic by deposition of the Damara Supergroup and development of the Pan-African belt. At that period, any tectonometamorphic event reportable to Grenville-Kibaran orogeny was not recognized in SW Angola.

Keywords: Eburnean belt, Chela Group, Mesoproterozoic bimodal magmatism, Pan-African belt, SW Angola.

Resumo: O Grupo Chela está conformado a uma sequência vulcano-sedimentar depositada em extensa bacia epicratónica localizada no SW de Angola. Por sua vez, o Grupo Chela assenta em discordância sobre um soco cratónico correspondente ao cinturão orogénico Eburneano, essencialmente formado por gnaisses e migmatitos, granitos peraluminosos sintectónicos foliados e granitos tardi a pós-tectónicos das Montanhas da Chela e Gandarengos. Aos granitos sintectónicos tem sido atribuída idade Rb/Sr de 2,1 ± 0,1 Ga e para o granito tardi-tectónico da Chela obteve-se a idade U-Pb sobre zircão de 1947 ± 5 Ma. Esta última datação isotópica permite referenciá-la como idade máxima para o Grupo Chela. Além disso, o granito porfiróide calco-alcalino da Serra de Gandarengos e uma massa de riolitos, espacialmente relacionados com este granito, revelaram, respectivamente, idades U-Pb sobre zircão de 1810 ± 11 Ma e 1814 ± 88 Ma. Os riolitos são intrusivos na Formação Tundavala da base do Grupo Chela e devem estar na origem dos piroclastitos característicos da Formação Humpata. O intervalo de tempo entre 1814-1810 Ma, obtido para o vulcano-plutonismo intrusivo no Grupo Chela, restringe a idade mínima deste Grupo e permite definir o intervalo 1947-1810 Ma como o principal período de deposição desta sequência sedimentar, em ambiente pós-orogénico.
Após a deposição do Grupo Chela, ocorreu um período de acreção crustal, mal estudado no SW de Angola, marcado pela instalação de granitos peraluminosos leucocráticos e por importante magmatismo bimodal do Mesoproterozóico (1,4-1,1 Ga), seguido, durante o Neoproterozóico, pela deposição do Supergrupo Damara e desenvolvimento do cinturão orogénico Pan-Africano. Naquele período, não foi reconhecido no SW de Angola qualquer episódio tectonometamórfico reportável ao orógeno Grenville-Kibariano.

Palavras-chave: Cinturão orogénico Eburneano, Grupo Chela, magmatismo bimodal Mesoproterozóico, Cinturão Pan-Africano, SW de Angola.

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1. Introduction

The Chela Group is a general term for a widespread volcano-sedimentary sequence, recognized by Correia (1973; 1976) in the region of Humpata (Lubango), SW Angola (Fig. 1). The author distinguished, from bottom to top, the following Formations: Tundavala, Humpata, Bruco and Cangalongue, the last outcropping south of the study area (Fig. 2).

In the past, the age and sedimentary environment of the Chela Group were controversial. This fact was due to their field relationships with mafic intrusive sills and dykes and to ancient K/Ar or Rb/Sr radiometric data, either obtained from the basement or from mafic dykes, which yielded ages ranging from Neoproterozoic to Paleoproterozoic times (Vale & Simões, 1971; Vale & Gonçalves, 1973; Silva *et al.*, 1973; Torquato & Amaral, 1973; Torquato, 1974a; Torquato *et al.*, 1979; Carvalho *et al.*, 1979; Kröner & Correia, 1980; Torquato & Carvalho, 1992; Carvalho *et al.*, 2000; McCourt *et al.*, 2004).

The lithostratigraphic similarity with geological units defined in Namibia led to the correlation, not only between the Chela Group and the Nosib Group, but also between the Leba Formation, that overlies the Chela Group, and the Otavi Group. Based on these lithological correlations, the Chela Group and the

Leba Formation were integrated into the Damara Supergroup of the Damara belt (Carvalho, 1969; Correia, 1973, 1976; Kröner & Correia, 1980).

Other units of southern Angola, such as the Iona Formation (Kröner & Correia, 1980), Cahama-Otchinjau Formation (Torquato & Salgueiro, 1977) and the large outcrop to the west of Ompupa (Carvalho & Alves, 1993), show lithostratigraphic similarities with Chela Group. However, we do not attempt a correlation between these units and the Chela Group, since they are not in geographical continuity. In addition, the Cahama-Otchinjau Formations are intruded by the A-type red granites with U-Pb zircon age of 1376 ± 2 Ma (Drüpel *et al.*, 2007) constraining their minimum age; and the Iona Formation, represented by a sequence of conglomerates, quartzitic sandstones, phyllites and arkoses, is overlain by the Tchamalindi Formation consisting of dolomitic limestone followed by the Caiombo Formation containing sandstones and siltstones. They are in geographic continuity with the Damara sequence of northern Namibia (Kröner *et al.*, 2010) and display tectonic deformation due to thrust to the East of the Pan-African mobile belts. Specifically, these belts are the Damara belt referred as the inland branch of the Damara orogen (Kröner, 1982; Martin, 1983; Miller, 1983; Prave, 1996) where the general E-W strike changes gently in a wide arc to the Kaoko belt, trending SSE-NNW along the coastline and continuing to the SW of Angola (Seth *et al.*, 1998; Passchier *et al.*, 2002; Goscombe & Gray, 2007; 2008). Alternatively, some authors linked the Chela Group and those correlated units of southern Angola to the Kibaran belt (Carvalho, 1972; Carvalho *et al.*, 1987).

The main purpose of this paper is to review the lithostragraphic sequence and depositional age of the Chela Group and its Eburnean basement in order to contribute to understand the Proterozoic crustal evolution of SW Angola, taking into account: i) the detailed field work and definition of the different Formations done in the Bibala region, aiming at the 1:100 000 scale geological Map of Angola (Pereira *et al.*, 2006); ii) the new whole-rock chemical composition of granitic rocks from the basement and associated porphyritic rhyolites intrusive into Chela Group; and iii) zircon U-Pb data from these basement granitic rocks and from rhyolites injected into the Tundavala Formation of the Chela Group as well. Isotopic U-Pb data from the basement and intrusive rocks were decisive to define the interval 1947-1810 Ma as the main period of deposition of the Chela Group in a shallow fluvial-marine environment.

2. Geological setting

The study area is part of the event that is generally referred in Africa to the Eburnean orogeny (Roques, 1948). This event affects a large portion of the central-western territory of Angola and is one of the most important orogenic belts that were successively accreted to the southern border of the Congo Craton, from the Archean to the Neoproterozoic (Fig. 1).

2.1. The pre-Chela Group basement

For the Archean belt, a high grade tectonometamorphic event (HP/HT) is recognized in central and NE of Angola, which is characterized by a gneiss, granulite and charnockite association. Geochronologic data have confirmed an age of 2.82 Ga to the charnockitisation episode (Cahen *et al.*, 1984), early identified between 2.85-2.9 Ga (Delhal *et al.*, 1976). In southern Angola, north of Bibala and SSW of Lubango, a Gneiss-migmatite Complex with minor occurrence of granitoid rocks and a Schist-quartzite-amphibolite Complex with marble layers, appear to be remnants of a pre-Eburnean basement but may have suffered Eburnean reworking (for more detail see Carvalho & Alves 1993; Carvalho *et al.*, 2000). In fact, on both banks of Cunene River, northwestern Namibia and south Angola, Kröner *et al.* (2010) defined the Epupa Metamorphic Complex which, according to these authors, extends to southern Angola. It consists of orthogneisses, migmatites and anatetic granites. The zircon protolith ages for the orthogneisses range from 1861 ± 3 to 1758 ± 3 Ma and anatexis in the migmatitic gneiss gives 1762 ± 4 Ma with a related granite zircon age of 1754 ± 4 Ma (Otjitanda Granite).

Pre-Eburnean crustal stretching and subsidence induces deposition of thick sedimentary and volcanic sequences which are well documented in central Angolan areas. These metamorphic sequences have a general NW-SE structural trend, showing a medium to rare high grade metamorphism and intrusion of a large amount of Eburnean granitoids. Some of them constitute the basement rocks of the Chela Group, in the Bibala area (Fig.2). The most common are the syntectonic, peraluminous granitoids; and, less common, the Chela granite and Gandarengos granite, late-tectonic, metaluminous granitoids.

The peraluminous granite is widespread, not only in the study area, but also in the entire Angolan territory, being appointed as the “regional granite” (Carvalho, 1984). This is an equigranular, mainly biotitic, deformed granite, to which has been attributed Rb/Sr age of 2.1 ± 0.1 Ga (Torquato *et al.*, 1979). Recently, McCourt *et al.*, (2004) reported SHRIMP upper intercept zircon ages of 2038 ± 28 Ma and 1959±6 Ma for the little deformed, supposedly peraluminous granites, directly underlying the Chela Group sediments. For the Chela and Gandarengos granites, free of tectonic deformation, the geochemical and isotopic data later developed in this study, revealed U-Pb zircon ages of 1947 ± 5 Ma and 1810 ± 11 Ma, respectively. After the emplacement of the late-tectonic granites, the region was sufficiently consolidated to be considered cratonized.

Subvolcanic rhyolites and porphyries, described below, are well exposed in the Lubango-Bibala area (Fig. 2) and they are confined to the neighborhood of the late-tectonic Gandarengos granite massif. As revealed by isotopic and lithogeochemical analysis, the rhyolitic porphyries, intrusive into Tundavala Formation at the base of the Chela Group, seem to be associated with this granite.

2.2. The Chela Group deposition and subsequent episodes

Subsequent to the Eburnean tectonometamorphic episode, the Chela Group was deposited as a wide-ranging epicratonic fluvial-marine basin. On the eastern side, the Chela Group forms the Humpata Plateau with 2280 m of maximum altitude emerging from an extensive plain developed at an average altitude of 1800 m; on the western side, erects a vigorous escarpment, with slopes above 1100 m, overlooking a littoral platform with 600 m average altitude. This sedimentary sequence extends southern of the Lubango region and even further south to the border with Namibia. Running nearly N-S, the Chela Group corresponds to a pile of sediments with a minimum thickness of six hundred meters. From the bottom to top, the sequence consists of the Tundavala, Humpata, Bruco and Cangalongue Formations, first defined in the Humpata Plateau, in the SW of Angola (Correia, 1973, 1976). The Leba Formation that unconformably overlies the Chela Group consists of dark dolomitic limestones with stromatholites (Fig. 3).

The Chela Group sedimentary environment shows a shallow epicontinental siliciclastic facies with interbedded cinerites and volcanoclastic rocks. Neither tectonic deformation nor metamorphism affected the sediments and volcanic rocks. Generally, the Tundavala Formation, with a variable thickness,

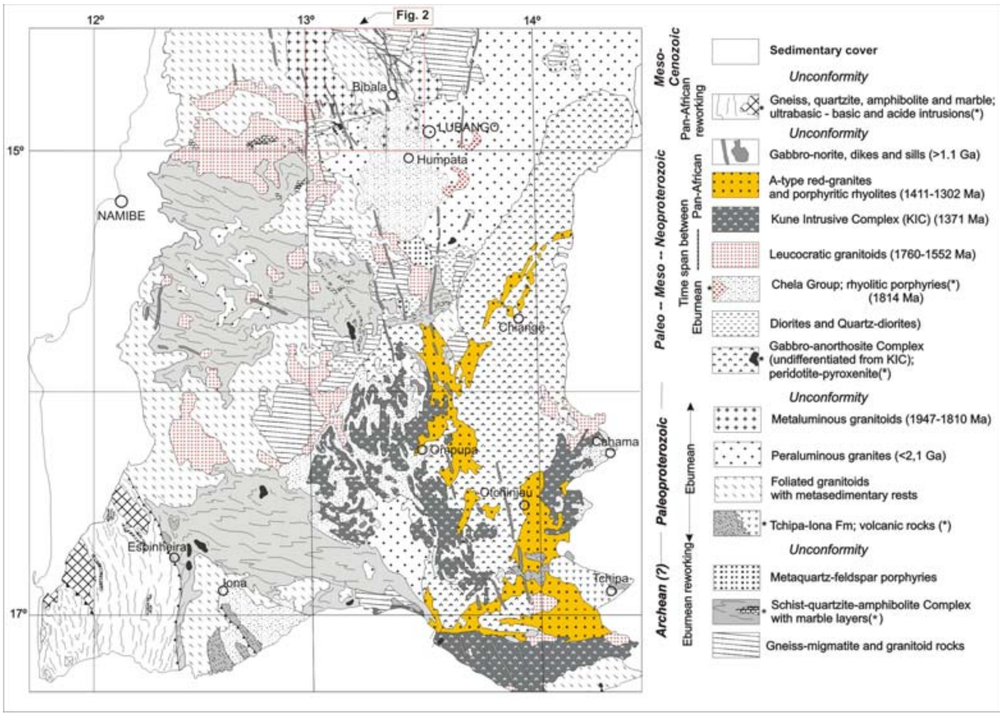

Fig. 1. Geological sketch map of the SW of Angola. (Adapted from Carvalho, 1982; Araújo *et al.*, 1988; Carvalho & Alves, 1993).

Fig. 1. Mapa geológico esquemático do SW de Angola. (Adaptado de Carvalho, 1982; Araújo *et al.,* 1988; Carvalho & Alves, 1993).

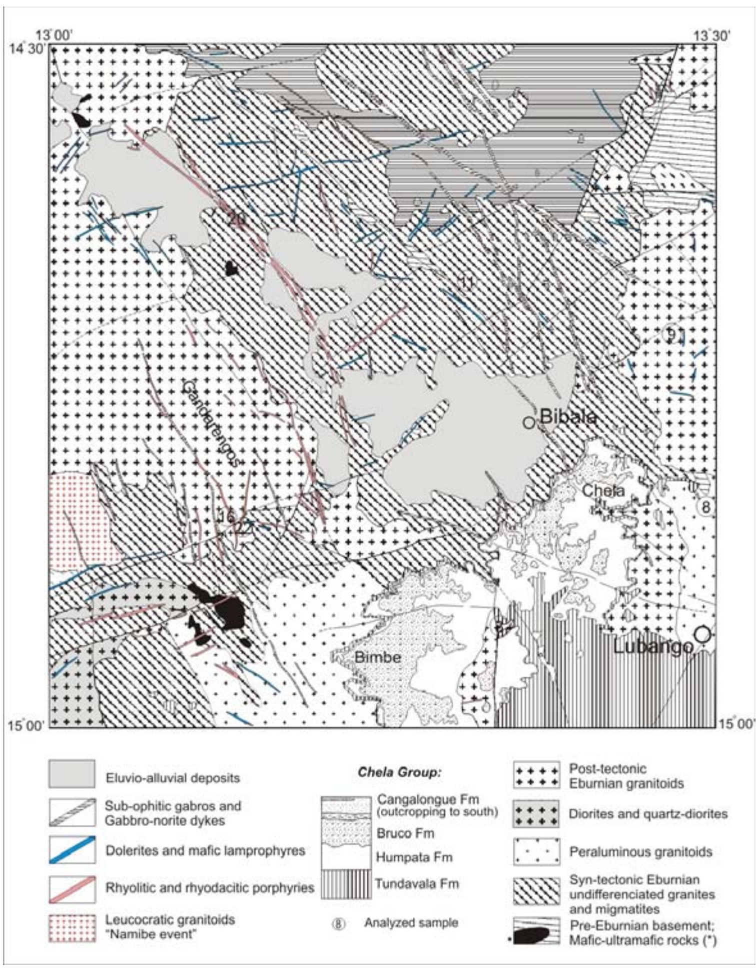

Fig. 2. Geological sketch map of the Lubango-Bibala region. (Adapted from the Angola Geological Map, 1: 100 000 scale; Pereira *et al.*, 2006).

Fig. 2. Mapa geológico esquemático da região de Lubango-Bibala. (Adaptado do Mapa Geológico de Angola, escala 1:100 000; Pereira *et al.,* 2006).

was deposited over an irregular Paleoproterozoic Eburnean granite substratum. This formation consists of discontinuous lenticular conglomerate and a sequence of quartz-sandstones and arkoses with cross-bedding structures. The Humpata Formation is characterized as containing pyroclastic materials and several levels of gritstone intercalations. The transition from the coarse sandstone of the Tundavala Formation to the red or cream-coloured volcanoclastic siltstone of the Humpata Formation, where observable, corresponds to a planar lithological unconformity. The top of this later unit is marked by an important erosive discordance. The Humpata Formation may show significant thickness reduction in places of pronounced erosive activity. In these cases, the base of the Bruco Formation may be initiated by a thick breccia of conglomeratic oligomictic nature, associated with erosive channels carved in the Humpata volcanoclastic rocks. The basal fanglomeratic breccias of the Bruco Formation also occur at Tchiingue, located in the Humpata Plateau (Pereira *et al.*, 2006). However, the base of the Bruco Formation can also be a ruditic conglomerate of lenticular geometry, less than two meters thick, as described in the Bipope valley of the Chela Plateau, (Correia, 1976). The two situations mentioned above indicate the beginning of a new siliciclastic cycle characteristic of the Bruco Formation. The transition from the Bruco Formation to the Cangalongue Formation is gradual and the boundary is marked by the first occurrence of shales and limestones. The Cangalongue Formation includes highly ferruginous sandstones overlain by red sandstones and red shales, siltstones and also carbonated rocks at the top. The transition between the Chela Group and the overlaying dolomitic limestone of the Leba Formation (Vale & Gonçalves, 1973) could be recognized both by a lithologic discontinuity or an erosive unconformity.

After the deposition of those sedimentary series, a magmatic episode is referred by some authors but not reported to a tectonometamorphic event. In fact, a group of leucocratic granites and stocks, more or less circumscribed, have been referred to the western region of Chela Mountain and southwestern of Angola. Several Rb/Sr ages such as 1761 ± 19 Ma, R_i = 0,701 (Carvalho *et al.*, 1979) and 1527 ± 40 Ma, R_i = 0,705 (Carvalho and Tassinari, 1992) were reported for these leucogranites. The same episode, named for the first time ”Thermotectonic Namibe Event” by Torquato (1974b), was detected in several granitic rocks of the Espinheira-Namibe region, SW end of Angola, to which the Rb/Sr age of 1700 Ma was obtained.

Within the age limits reported for the ”Thermotectonic Namibe Event”, other more precise ages have been found in nortwestern Namibia, such as U-Pb ages mentioned before in the Epupa Metamorphic Complex (Kröner *et al.*, 2010) for migmatization and emplacement of peraluminous granites, respectively, 1762 ± 4 Ma and 1754 ± 4 Ma (Otjitanda Granite). Further south, the Frazfontein Granitoid Suite was defined with a concordant U-Pb age of 1662 ± 30 Ma (Burger *et al.*, 1976). Also in the NW Namibia, another metamorphic event was reported for the Epembe Unit, dated at 1.6-1.45 Ga (Seth *et al.*, 2003, 2005). It is assumed to be an early Mesoproterozoic orogenic event. The first age corresponds to the sedimentation and the second age to the granulite facies metamorphism.

However, after the deposition of the Chela Group, these latter tectonometamorphic episodes were not recognized so far in SW of Angola. The crustal growth in the region underwent a prolonged extensional Mesoproterozoic episode which includes: i) voluminous mafic magmatism, refered in the literature as the Kunene Igneous Complex (KIC), yielding a minimum age for cooling or emplacement, both provided by U-Pb aging of 1371 ± 2 Ma from a late-stage mangerite vein intrusive in the Quihita region (Mayer *et al.*, 2004) or by U-Pb SHRIMP ages of 1385 ± 7.6 Ma (McCourt *et al.*, 2004) from a mangerite dike intruding the massive anorthosites in the same region of SW Angola (these ages are concordant with the U-Pb zircon age of 1385 ± 25 Ma (Druppel *et al.*, 2000; 2007) obtained in the KIC of northern Namibia); ii) felsic magmatism represented, in southern Angola, by A-type red granites, syenites, porphyries and volcanics dated at several localities by Rb-Sr whole-rock isochrones with ages between 1411 ± 24 and 1302 ± 20 Ma (Torquato *et al.*, 1979; Bassot *et al.*, 1981; Silva & Simões, 1982; Carvalho *et al.*, 1987) and, in northern Namibia, by the red

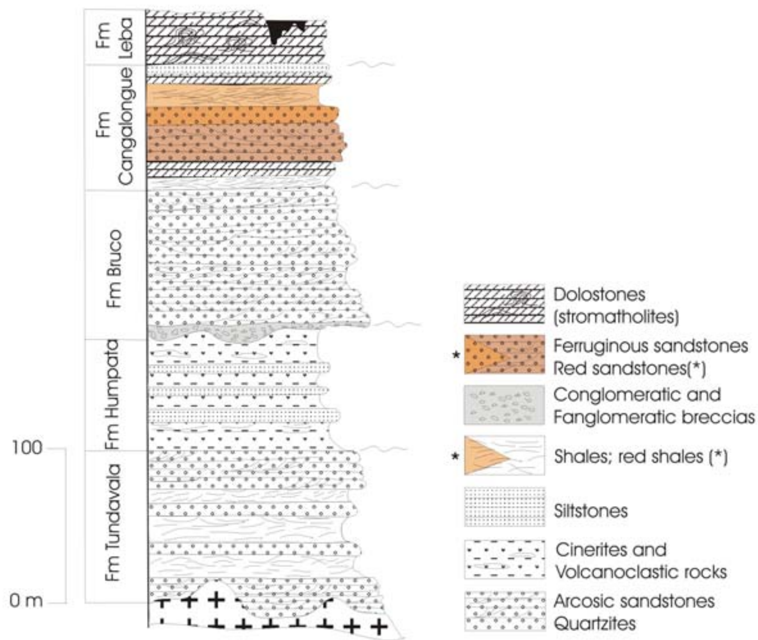

Fig. 3. Lithostratigraphic sequence of the Chela Group.

Fig. 3. Sequência litostratigráfica do Grupo Chela.

granitic rocks associated with anorthosites with a U-Pb zircon age of 1376 ± 2 Ma (Drüpel *et al.*, 2007); iii) finally, several sills and dykes of dolerites, sub-ophitic gabbros and noritic gabbros forming extensive intrusions included in the 1.1 to 1.2 Ga age range (Carvalho *et al.*, 1979)

2.3. The Neoproterozoic belt

No tectonometamorphic episode was recognized in the interval between the bimodal magmatism described above and the deposition of the Damara Supergroup of the Pan-African belt, in the SW of Angola. Consequently, the evidence for within plate bimodal magmatism in the Mesoproterozoic strongly suggests that the region underwent a very long extensional regime incompatible with a regional tectonometamorphic event involving the Grenville-Kibaran belt.

It is assumed that the Damara-Kaoko belt, which occurs in the NW of Namibia and SW of Angola (Kröner, 1982; Porada & Behr, 1988; Porada, 1989), evolved from a continental rift which affected the West-Gondwana continent around 1000 Ma ago, immediately after the Grenvillian-Kibaran event. It represents the marginal and more recent orogenic belt of the southern part of the Congo Craton. The Damara Supergroup includes, from bottom to top, the Nosib Group, the Otavi Group and the Mulden Group (SACS, 1980), forming a thick sequence with the opening of a triple point ocean, materialized by the Matchless amphibolites (780-760 Ma, e.g. Miller, 1983) on the Damara belt. More recently, structural analysis and isotope geology research have been undertaken at the Kaoko belt of NW Namibia in order to provide refined ages and tectonic constraints. This belt integrates the Damara orogen (Kröner *et al.*, 2004; Gray *et al.*, 2006; Goscombe & Gray, 2008).

In SW Angola, the Damara-Kaoko belt is not well known. In this area, a poorly documented metasedimentary sequence was affected by a high metamorphic grade along the western branch of the Kaoko belt (Torquato, 1974b). This sequence was thrusted towards the east, in a transpressional convergence, over another sequence that shows amphibolitic metamorphic facies. The polymetamorphic stage, lithologic diversity and mainly the poor knowledge of the Angolan occidental band, comparatively to the NW of Namibia (Goscombe & Gray, 2007; 2008), do not enable an effective correlation between the two sections of the Kaoko belt. A lower structural level is present in SW Angola, suggesting an older metamorphic event which affects an undifferentiated sequence which is later reworked in the Pan-African orogeny.

3. Analytical procedures

The whole-rock chemical compositions, listed in Table 1 were obtained at "Laboratório Nacional de Energia e Geologia" (LNEG) (Porto-Portugal): i) for the major and minor elements (5% maximum accuracy), the samples were pressed in a Herzog HTP 40 and analysed by X-ray Fluorescence Spectrometry (XRF), with dispersing λ PW2404-PANalytical, with previous calcination at 1050 °C and fusion at 1150 °C; ii) for the REE, the samples were analysed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), using sample decomposition and sintering with Na_2O_2. The overall results were validated with standards of the Geopt Proficiency-testing Program. The precision of this technique is discussed in detail by Machado & Santos (2006).

The isotopic analyses were carried out at "Centro de Pesquisas Geocronológicas" (CPGeo) of the University of São Paulo, Brasil. The analytical results are shown in Tables 2 and 3. The Sm-Nd analyses were prepared using standard methods according to the analytical procedures described by Sato *et al.* (1995), involving HF-HNO_3 dissolution, plus HCl cation exchange. No visible solid residues were observed after dissolution. Samples with incomplete dissolution were discarded. The Nd ratios were normalized to a $^{146}Nd/^{144}Nd$ = 0.72190. The averages of $^{143}Nd/^{144}Nd$ for La Jolla and BCR-1 standards were 0.511847 ± 0.00005 (2σ) and 0.512662 ± 0.00005 (2σ) respectively. The blanks were less than 0.03 ng.

Zircon crystals were concentrated by means of crushing and milling in jaw crushers and disc mills, sieving, density separation using the Wilfley table, heavy liquids (bromoform and methylene iodide) and electromagnetic separation using a FRANTZ isodynamic separator. For the U-Pb (TIMS: thermal ionization mass spectrometry) a final selection of zircon crystals was carried out manually under the stereomicroscope. For the U-Pb (TIMS) analyses, 10-15 zircon crystals were selected, which, after washing, were dissolved in Teflon beakers. U and Pb were isolated in anionic resin columns, according to the procedures described in Basei *et al.* (1995), adapted from Krogh (1973, 1982) and Parrish (1987). Isotope ^{205}Pb was used as spike; the total blank obtained was ≈10 pg. The measurements were performed by the multicollector mass spectrometer FINNIGAN MAT-262 (Sato & Kawashita, 2002). At CPGeo, the average values obtained for the NBS-981 and NBS-983 standards were respectively $^{204}Pb/^{206}Pb$ = 0.05903 ± 0.02% and 0.000368 ± 3%; $^{207}Pb/^{206}Pb$ = 0.91479 ± 0.01% and 0.071212 ± 0.05%, and $^{208}Pb/^{206}Pb$ = 2.1675 ± 0.01% and 0.013617 ± 0.06%, with annual variation of 1σ. The fractionation correction factor used for normalization was 0.095% a.m.u. (atomic mass unit). Ages were calculated using the ISOPLOT program (Ludwig, 2003) and presented with the corresponding 2σ deviations. The constants used are those recommended by Steiger & Jager (1977).

4. Petrography and whole-rock chemical compositions

Samples from the Chela and Gandarengos late-tectonic granites and porphyritic rhyolites intrusive into the Chela Group were selected for petrographic studies and whole-rock chemical analyses. The location of the samples is listed in Table 4.

4.1. Granitoid rocks

The granitoid rocks are divided into two major groups: the syntectonic granites (two mica foliated granitoids) and the late-tectonic granites (Chela and Gandarengos granites).

The syntectonic Eburnean granitoids. These rocks occupy large areas of the SW of Angola. They are heterogeneous rocks with a large variety of facies that may grade from migmatitic to equigranular or porphyritic. The migmatitic and gneissic units show diffuse contacts, including metasedimentary enclaves, schlieren structures, and most of them display a N40°-50°W subvertical foliation trend (Pereira *et al.*, 2001).

They vary in composition from quartz-diorite to granite and consist of quartz, oligoclase (An_{20}), microcline, primary biotite and also neoformed unaltered albite and muscovite. The subordinated compounds include quartz-plagioclase myrmekites, ilmenite, apatite, sphene, epidote, chlorite and very rarely hornblende (only in quartz-diorite composition).

The syntectonic granites are slightly peraluminous (Fig 4-A, Maniar & Picoli, 1989), with a lower content in incompatible elements such as Ti, Zr, Y. They display moderate Ba and REE content (Ba = 840-989 ppm; ΣREE = 152-383 ppm), low LREE enrichment in the (335-8) gneiss-granitoid and high LREE enrichment in the (335-11) migmatitic granite (La_N/Yb_N = 8.7-59) and respectively moderate or almost unnoticeable Eu negative anomalies (Eu/Eu* = 0.5-1) calculated according to Taylor & McLennan (1985). In spite of the syn-collisional chemical affinity revealed in the diagram (Fig. 4-B, Batchelor & Bowden, 1985), it is evident that the peraluminous granites have different crustal evolution, as is suggested by their REE patterns (Fig. 4). The I-S transitional character of these granites (Chappel & White, 1974; White & Chappel, 1977), and the $^{87}Sr/^{86}Sr$ R_i = 0.702 (Torquato *et al.*, 1979), can be explained by anatexis of mixed crustal components.

The late-tectonic Eburnian granites. They are homogeneous granitoids with pink color, showing reddish color tendency along fractured and confined zones. They also present isotropic equigranular texture, and a medium to coarse grained, locally porphyritic character. No signs of ductile deformation were observed.

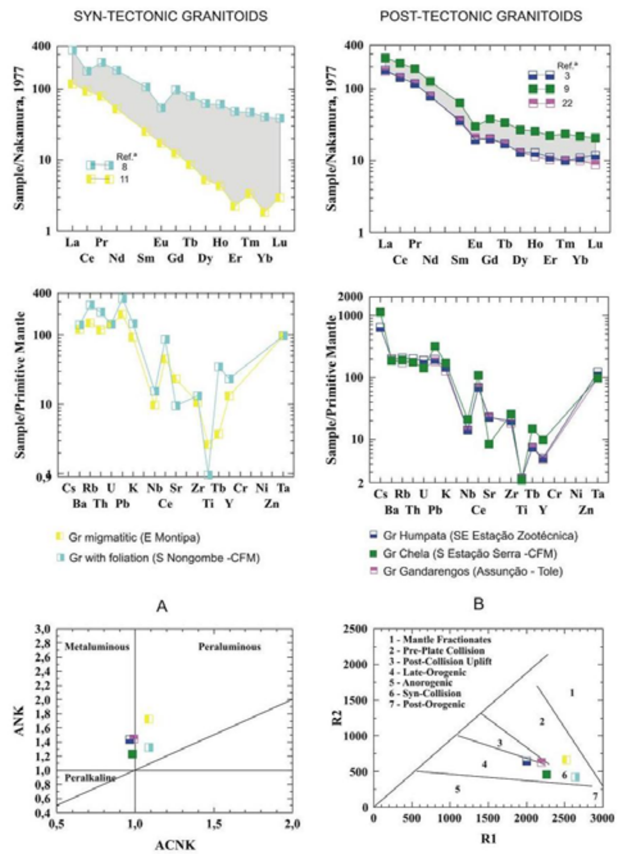

Fig. 4. Chondrite-normalized REE patterns (Nakamura, 1977) of syn and post-tectonic Eburnean granitoids from the Lubango-Bibala region; multielementary diagrams sample / primitive mantle of syn and post-tectonic Eburnean granitoids from the Lubango-Bibala; A) A/CNK – A/NK, (Maniar & Picoli, 1989); B) R1=4Si-11(Na+K)-2(Fe+Ti), R2=6Ca+2Mg+Al, (Batchelor & Bowden, 1985).

Fig. 4. Padrões de ETR normalizados para condrito (Nakamura, 1977) de granitóides Eburneanos sin e pós-tectónicos da região de Lubango-Bibala; diagramas multielementares amostra / manto primitivo de granitóides Eburneanos sin e pós-tetctónicos de Lubango-Bibala; A) A/CNK – A/NK, (Maniar & Picoli, 1989); B) R1=4Si-11(Na+K)-2(Fe+Ti), R2=6Ca+2Mg+Al, (Batchelor & Bowden, 1985).

The composition is granitic or rarely granodioritic with biotite and hornblende as essential minerals. The K-feldspar is microcline-perthite and sodic microcline. The plagioclase is zoned, euhedral to subeuhedral, of oligoclase domain or also albite formed by post magmatic alteration. The megacrystals, when present, are also of zoned microperthitic microcline, marking several crystallization stages, considering that they present edges of biotite plus quartz and are marginated by a rapakivi feature with intergrowth of microcline and albite. Zircon, rutile, ilmenite, apatite, alanite, sphene, muscovite and epidote, could be observed among the accessory and secondary components.

The late-tectonic granites of the Chela and Gandarengos Mountain show a slightly metaluminous composition with a low content in HFS elements such as Zr, Y, Ti (Fig. 4). They exhibit moderate to high Ba and REE contents (Ba = 1313-1384 ppm; REE = 228-358 ppm), moderate LREE and low HREE enrichment with a steep REE pattern (La_N/Yb_N = 12-17) and a not pronounced Eu negative anomaly (Eu/Eu* = 0.6-0.7). In spite of the absence of ductile deformation and a late orogenic character which is pointed out by the Batchelor & Bowden (1985) diagram (Fig. 4 B), the Chela and Gandarengos granites show mineralogical and chemical metaluminous composition, suggesting a calc-alkaline component in their magma source, or hybridization of crustal components with mantle-derived materials (Downes & Duthou, 1988; Dias *et al.*, 1998; Dias *et al.*, 2002).

4.2. The felsic porphyries and rhyolites

The felsic porphyries are subvolcanic rocks that occur as dykes with overall orientation NNW-SSE to N-S, either surrounding or intruding the Gandarengos granite pluton (Fig. 2 and Fig. 5). On the Leba road between Humpata and Caraculo (sheet 355 - Humpata-Cainde, of the Geological Map of Angola), we can also observe a large rhyolitic mass, that is controlled by fault systems, intruding the Tundavala Formation (samples 355-1; 355-2; 355-21, Table 1). The marginal faults that control the rhyolitic mass emplacement also mark the feeding channels of the pyroclastic flow rocks, described in the present work as the Humpata Formation of the Chela Group.

All lithotypes are felsic leucocratic porphyritic rocks, with megacrystals of quartz, plagioclase and potash feldspar, included in a phaneritic granophyric matrix, sometimes spherulitic. The quartz megacrysts have corroded gulfs; the plagioclase is normally euhedral albite, but locally ranging to oligoclase (An_{20}); K-feldspars are orthoclase (only in felsic porphyries) and sanidine which occurs in small quantity. The matrix of the felsic porphyry dikes is quartz-feldspatic, mainly microcrystalline. Locally, scarce percentages of muscovite, chlorite and epidote result from the plagioclase alteration.

The chemical analyses are shown in Table 1 and Fig. 5. REE were analysed by ICP-Ms in samples 355-1, 356-2 and 356-3; in the remaining samples of felsic porphyries and rhyolites, REE are indicative records analyzed by XRF. All of them show high LIL elements enrichment, with Ba, Nb, Sr negative anomalies compared with the lower crust. REE content is moderate to high (ΣREE = 112-565 ppm) showing high LREE and low HREE enrichment (La_N/Yb_N = 9.81-53) and an inexpressive Eu negative anomaly (Eu/Eu* = 0.9-0.57).

Based on the log (Zr/TiO_2)-log (Nb/Y) diagram (Winchester & Floyd, 1977), a general rhyodacitic-dacitic classification was applied to the hypabyssal rocks of the Bibala-Lubango region. The log Rb–log (Y+Nb) discriminative diagram (Pearce *et al.*, 1984) reveals volcanic arc signature for these rocks (Fig. 5A), which in some way is in agreement with the syn-collisional to post-orogenic tendency (Fig.5B) expressed in the diagram R1 = 4Si-11 (Na + K) -2 (Fe + Ti), R2 = 6Ca +2 Mg + Al (Batchelor & Bowden, 1985).

The relative proximity between the age of rhyolite and Gandarengos granite, as well as, the petrochemical characteristics of both, suggest that the felsic porphyries and rhyolites may have originated in a subvolcanic enriched magma derived from the fractioned granitic magma.

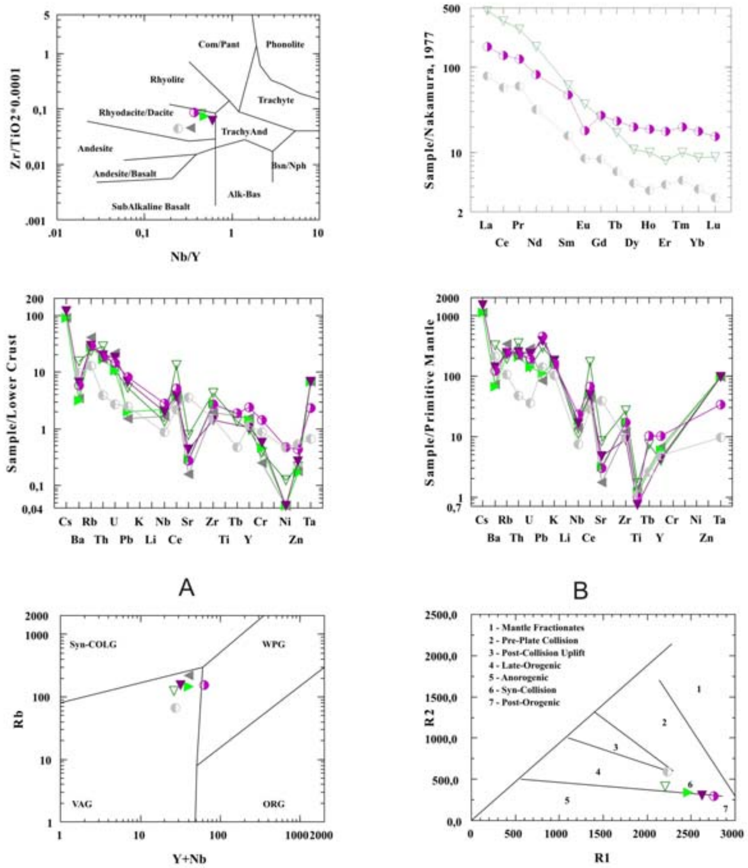

Fig. 5. Log (Zr/TiO2)-log (Nb/Y), classification diagram, (Winchester & Floyd, 1977); chondrite-normalized REE (Nakamura, 1977) of rhyolites and rhyolitic porphyries from the Lubango-Bibala region; multielementary diagrams of sample / lower crust and primitive mantle; A) Log Rb – log(Y+Nb) discrimination diagram, (Pearce et al., 1984); B) R1=4Si-11(Na+K)-2(Fe+Ti), R2=6Ca+2Mg+Al, (Batchelor & Bowden, 1985).

Fig. 5. Log (Zr/TiO2)-log (Nb/Y), diagrama de classificação, (Winchester & Floyd, 1977); ETR normalizados para condrito (Nakamura, 1977) de riolitos e pórfiros riolíticos da região de Lubango-Bibala; diagramas multielementares de amostra / crusta inferior e manto primitivo; A) Diagramas descriminantes Log Rb – Log(Y+Nb), (Pearce *et al.*, 1984); B) R1=4Si-11(Na+K)-2(Fe+Ti), R2=6Ca+2Mg+Al, (Batchelor & Bowden, 1985).

Table 1. Whole-rock major and trace elements data for acid rocks from Lubango-Bibala region.

Tabela 1. Análises em rocha-total de elementos maiores e traço de rochas ácidas da região de Lubango- Bibala.

	Syn-tectonic granites		Late-tectonic granites			Rhyolites			Granite porphyries			
Sample	335-8	335-11	335-3	335-9	335-22	355-1	355-2	355-21	356-2	356-3	335-16	335-20
SiO2	73.36	68.38	66.49	71.17	68.25	70.39	74.29	75.16	76.53	69.31	73.27	73.81
Al2O3	13.64	15.46	15.49	13.72	15.08	14.73	13.53	12.24	12.42	15.5	13.21	13.10
Fe2O3 t	1.89	3.38	3.87	2.85	3.56	2.47	2.16	2.21	1.53	2.55	2.38	2.24
MnO	0.05	0.05	0.08	0.06	0.07	0-03	0.02	0.03	0.06	0.07	0.05	0.03
CaO	1.27	2.89	2.68	1.53	2.62	0.96	0.12	0.45	0.45	2.32	0.76	0.63
MgO	0.37	1.11	1.13	0.54	1.03	0.43	0.98	0.30	0.07	0.86	0.20	0.30
Na2O	3.35	3.62	3.72	3.41	3.84	3.25	1.63	3.02	3.33	4.54	3.09	3.46
K2O	4.40	2.79	4.33	5.15	3.84	5.44	4.64	5.37	4.82	3.06	5.90	4.98
TiO2	0.21	0.57	0.50	0.48	0.52	0.37	0.30	0.16	0.22	0.24	0.27	0.26
P2O5	0.07	0.17	0.15	0.10	0.17	0.06	0.05	0.03	<0.03	0.1	0.04	0.04
Loi	0.99	1.34	1.25	0.58	0.66	1.47	2.03	0.73	0.4	1.25	0.40	0.90
Rb	170	95	129	120	110	124	218	155	153	67	153	146
Sr	200	495	474	176	485	179	37	101	63	831	145	67
Y	106	6	23	44	22	18	30	20	46	22	24	27
Zr	150	120	224	289	203	303	137	99	190	106	195	194
Nb	11	7	10	15	10	8	10	12	16.9	5.3	13	13
Ba	989	840	1384	1313	1344	2275	517	996	861	1469	639	469
Ta	<5	<5	<5	<5	<5	<5	<5	<5	1.4	0.40	<5	<5
Sn	<6	<6	<6	<6	<6	6	7	<6	nd	nd	<6	<6
W	16	8	<6	<6	<6	41	<6	<6	nd	nd	<6	<6
Th	18	10	17	15	15	30	18	21	19.3	4.1	19	18
Hf	<5	5	8	7	5	6	<5	<5	6.3	2.6	6	5
U	<4	<4	4	<4	<4	<4	6	5	4.0	0.75	<4	<4
Cs	<10	<10	<10	<10			<10	12	nd	nd	10	<10
Ni	11	11	<7	<7	9	17	<7	<7	65	63	<7	<7
Cu	<6	7	42	14	16	26	17	26	<6	<6	23	13
Zn	49	64	47	55	47	18	15	22	36	45	14	14
Pb	24	14	14	23	13	21	6	27	32	10	22	8
Sc	nd	nd	9	7	nd	nd	<7	<7	<7	<7	<7	<7
V	16	58	46	22	40	10	20	5	8	29	8	6
Cr	57	53	52	49	45	91	59	136	338	203	94	110
Co	6	6	7	<5	7	<5	<5	<5	<5	5	<5	<5
Ga	18	21	17	17	17	15	25	13	15	15	14	16
La	116	39	59	87	57	151	111	59	57.4	26.4	53	58
Ce	154	80	122	192	122	304	78	86	119	50.2	91	93
Pr	26.2	8.8	13.2	21.1	13.2	31.4	nd	nd	13.9	5.7	nd	nd
Nd	113	33	49	79	49	110	63	38	51.6	20.3	31	43
Sm	21.3	5.1	7.2	12.7	7.4	12.5	8	9	9.6	3.2	4	11
Eu	4.2	1.3	1.5	2.3	1.6	2.8	nd	nd	1.4	0.66	nd	nd
Gd	26.9	3.4	5.6	10.4	5.5	7.1	nd	nd	7.5	2.3	nd	nd
Tb	3.7	0.4	0.8	1.6	0.8	0.8	nd	nd	1.1	0.28	nd	nd
Dy	21.3	1.8	4.4	9.1	4.4	3.7	nd	nd	6.8	1.5	nd	nd
Ho	4.2	<0.4	0.9	1.8	0.8	0.7	nd	nd	1.3	0.25	nd	nd
Er	10.7	0.5	2.5	5.0	2.3	1.8	nd	nd	4.0	0.94	nd	nd
Tm	1.4	<0.4	<0.4	0.7	<0.4	<0.4	nd	nd	0.60	0.14	nd	nd
Yb	8.8	<0.5	2.4	4.7	2.2	1.9	<6	<6	3.9	0.81	<6	<6
Lu	1.3	<0.2	0.4	0.7	0.3	0.3	nd	nd	0.52	0.10	nd	nd

nd: not analysed; <10: below detection limit

5. Geochronology and isotope geochemistry

Samples from the late-tectonic Chela and Gandarengos granites, porphyries and associated rhyolites intrusive into the Tundavala Formation of the Chela Group have been analyzed by U-Pb on zircons and Sm-Nd on whole-rock and mineral concentrates, in order to obtain their ages and characterize the nature of their magma sources. The analytical results are listed on Tables 2 and 3.

5.1. Late-tectonic granites

Ten zircon fractions separated from a sample of the Chela late-tectonic granitoid (sample 335-9) were analyzed by the U-Pb (TIMS) technique. The zircons are essentially subeuhedral, elongated and doubly terminated prisms. The fractions define a discordia with upper intercept U-Pb age of 1947 ± 5 Ma, with an MSWD of 29, indicating scattering of some analytical points (Fig. 6 A). The lower intercept provides an U-Pb age around 80, without geological meaning. The upper intercept age is interpreted as the time of the zircon crystallization and the age of the granitoid emplacement.

Table 2. U-Pb zircon analytical results of: rhyolite intrusive in Tumdavala Formation, Chela granite and porphyritic Gandarengos granite.

Tabela 2. Resultados analíticos U-Pb sobre zircões de: riolitos intrusivos na Formação Tundavala, granito da Chela e granito porfiróide de Gandarengos.

Sample	Fraction	207/235#	Error (%)	206/238#	Error (%)	Coef.	238/206	Error (%)	207/206#	Error	206/204*	Pb (ppm)	U (ppm)	Weight (mg)	206/238 Age (Ma)	207/235 Age (Ma)	207/206 Age (Ma)
355-2 Rhyolite	NM(1) A	4.096510	0.50	0.274896	0.49	0.987	3.637739	0.99	0.108079	0.08	1698.12	70.77	224.8	0.02761	1566	1654	1767
	NM(-1) B	3.699080	0.53	0.248947	0.50	0.941	4.016919	0.94	0.107767	0.18	1872.62	57.48	203.9	0.0177	1433	1571	1762
	M1+NM-1 C	3.773780	0.47	0.257281	0.47	0.991	3.886801	0.99	0.106382	0.06	3032.08	100.47	343.1	0.014	1476	1587	1738
	NM(1) D	3,424190	0.50	0.236424	0.49	0.982	4.229689	0.98	0.105042	0.09	2376.34	75.20	280.9	0.01064	1368	1510	1715
	M-1+NM-1E	3.589010	0.52	0.244533	0.51	0.978	4.089428	0.98	0.106448	0.11	5996.68	56.38	205.8	0.03163	1410	1547	1740
335-9 Granite	M(-2) F	5.197440	0.52	0.316681	0.50	0957	3.157752	0.96	0.119033	0.15	1374.72	50.91	130.2	0.01679	1774	1852	1942
	M(-2) G	2,404500	0.70	0.150200	0.63	0.914	6.657790	0.91	0.116106	0.28	279.65	46.16	219.2	0.01384	902	1244	1897
	M(-2) H	5.292630	0.49	0.323095	0.48	0.985	3.095065	0.99	0.118807	0.08	664.34	45.08	110.0	0.02359	1805	1868	1938
	M(-2) I	4.953020	0.74	0.305088	0.69	0.943	3.277743	0.94	0.117745	0.25	542.72	48.62	123.8	0.00642	1717	1811	1922
	M(-2) J	5.413720	0.57	0.328325	0.56	0.988	3.045763	0.99	0.119589	0.09	3109.42	35.95	90.2	0.01663	1830	1887	1950
	M(-2)B	5.278700	0.57	0.321606	0.56	0.989	3.109395	0.99	0.119042	0.08	1282.17	25.39	64.0	0.03119	1798	1865	1942
	M(-2)C	5.188880	0.54	0.316381	0.52	0.978	3.160746	0.98	0.118949	0.11	1289.12	29.39	74.6	0.03041	1172	1851	1941
	M(-2)D	5.199380	0.55	0.316160	0.54	0.982	3.162955	0.98	0.119273	0.10	1881.34	25.53	65.3	0.03242	1771	1853	1945
	M(-2)E	5.237610	0.51	0.318633	0.50	0.992	3.138407	0.99	0.119218	0.07	1821.32	37.21	93.8	0.03034	1783	1859	1945
	M(-2)A	5.343300	1.15	0.333353	0.67	0.602	2.999823	0.60	0.116253	0.92	470.60	32.32	72.1	0.02975	1855	1876	1899
335-22 Porphyrtic Granite	M(-2) F	4.590740	0.49	0.303306	0.49	0.989	3.297000	0.99	0.109774	0.07	3077.38	84.99	224.9	0.01096	1708	1748	1796
	M(-2) G	4.181460	0.51	0.277379	0.49	0.966	3.605176	0.97	0.109333	0.13	1991.38	58.72	171.7	0.01441	1578	1670	1788
	M(-2) H	4.42545	0.504	0.292441	0.492	0.9771	3.419493	0.98	0.109753	0.107	4846.775	74.731	214.76	0.01263	1653,7	1717	1795
	M(-2) I	3.87446	0.545	0.258693	0.519	0.9567	3.865586	0.96	0.108624	0.158	1071.154	70.115	215.9	0.00794	1483,2	1608	1777
	M(-2)A	4,575060	0.55	0.302372	0.55	0.991	10.94890 5	0.99	0.109737	0.07	5009.64	47.00	124.3	0.03199	1703	1745	1795
	M(-2)B	4.765980	0.50	0.312347	0.49	0.988	12.17038 5	0.99	0,110666	0.08	4325.24	65.21	166.3	0.03069	1752	1779	1810
	M(-2)E	4.572010	0.49	0.302626	0.49	0.992	12.37113 4	0.99	0.109572	0,06	2261.99	75.93	200.8	0.01859	1704	1744	1792
	M(-2)C	4.625470	0.54	0.304012	0.53	0,990	11.25703 6	0.99	0.110348	0.07	2357.88	58.81	152.6	0.03028	1711	1754	1805

Fractions: numbers in parentheses indicated the number of grains handpicked; # Radiogenic Pb corrected for blank and initial Pb; U corrected for blank; Total U and Pb concentrations corrected for analytical blank; Ages: given in Ma using Ludwig Isoplot/Ex program (1998), decay constants recommended by Steiger & Jäger (1977).
* Not corrected for blank or non-radiogenic Pb; M: magnetic fractions; NM: Non magnetic fractions

The same sample of the late-tectonic granitoid yielded a TDM age of 2.6 Ga which implies that intracrustal processes may have been important during the rock-forming episodes and this rock must have been formed by partial melting of late Archean continental rocks. The negative εNd value of -5.3, calculated to 1.95 Ga, is in accordance with the crustal origin established for the latetectonic granitoids of the Chela Mountain.

5.2. Rhyolitic porphyries and associated felsic subvolcanic rocks

Five zircon fractions, extracted from the rhyolitic porphyries (sample 355-2) which are intrusive into the Tundavala Formation of the Chela Group, are composed by euhedral, transparent and slightly pink crystals. The fractions, with discordant ages due to partial lead loss by continuous diffusion, define a discordia with an upper intercept age of 1814 ± 88 Ma, with a very high MSWD of 113, indicating scattering of analytical points (Fig. 6 B). The large 2σ error of the age is due to important zircon lead loss and scattering of analytical points. The age 1.8 Ga is interpreted as close to the timing of rhyolite emplacement. The possibility of the analyzed zircon grains to be detrital crystals, belonging to older continental rocks and to be assimilated by the rhyolitic magma is discarted, because the all individual $^{207}Pb/^{206}Pb$ ages are very homogenous with values around 1.7 Ga, what it is not expected for detrital zircon.

Table 3. Sm-Nd analytical results of: rhyolites, granite porphyry and granites from Bibala-Lubango region, SW of Angola.

Tabela 3. Resultados analíticos Sm-Nd de: riolitos, pórfiros graníticos e granitos da região de Lubango-Bibala, SW de Angola.

Samplen*	Type	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	Error	$^{143}Nd/^{144}Nd$	Error	$f_{Sm/Nd}$	$T_{DePaolo}$ (Ga)	$\varepsilon_{(0)}$
335-3	WR/Granite	7.327	43.552	0.1017	0.0003	0.511303	0.000008	-0.48	2.4	-26.04
335-9	WR/Granite	10.241	57.962	0.1068	0.0004	0.511224	0.000010	-0.46	2.6	-27.57
335-20	WR/Granite porphyrie	7.401	43.750	0.1023	0.0003	0.511340	0.000010	-0.48	2.3	-25.31
355-21A	WR/Rhyolit e	6.743	43.659	0.0934	0.0003	0.511244	0.000009	-0.53	2.3	-27.20
355-21	WR/Rhyolit e	7.088	47.077	0.0910	0.0003	0.511241	0.000013	-0.54	2.2	-27.25
335-22	WR/Granite	6.752	41.072	0.0994	0.0003	0.511281	0.000009	-0,49	2.4	-26.48

Eight zircon fractions, separated from samples of the Gandarengos (sample 335-22) late-tectonic porphyritic granite, define, within the Concordia U-Pb diagram, a discordia with an upper intercept age of 1810 ± 11 Ma (Fig. 6 C), interpreted as the timing of zircon crystallization and close to the emplacement of the body. This age is strongly connected with the zircon U-Pb age obtained for the associated rhyolite, which reinforces the hypothesis that the porphyritic granites and rhyolites have been derived from the same magmatic processes at the same time.

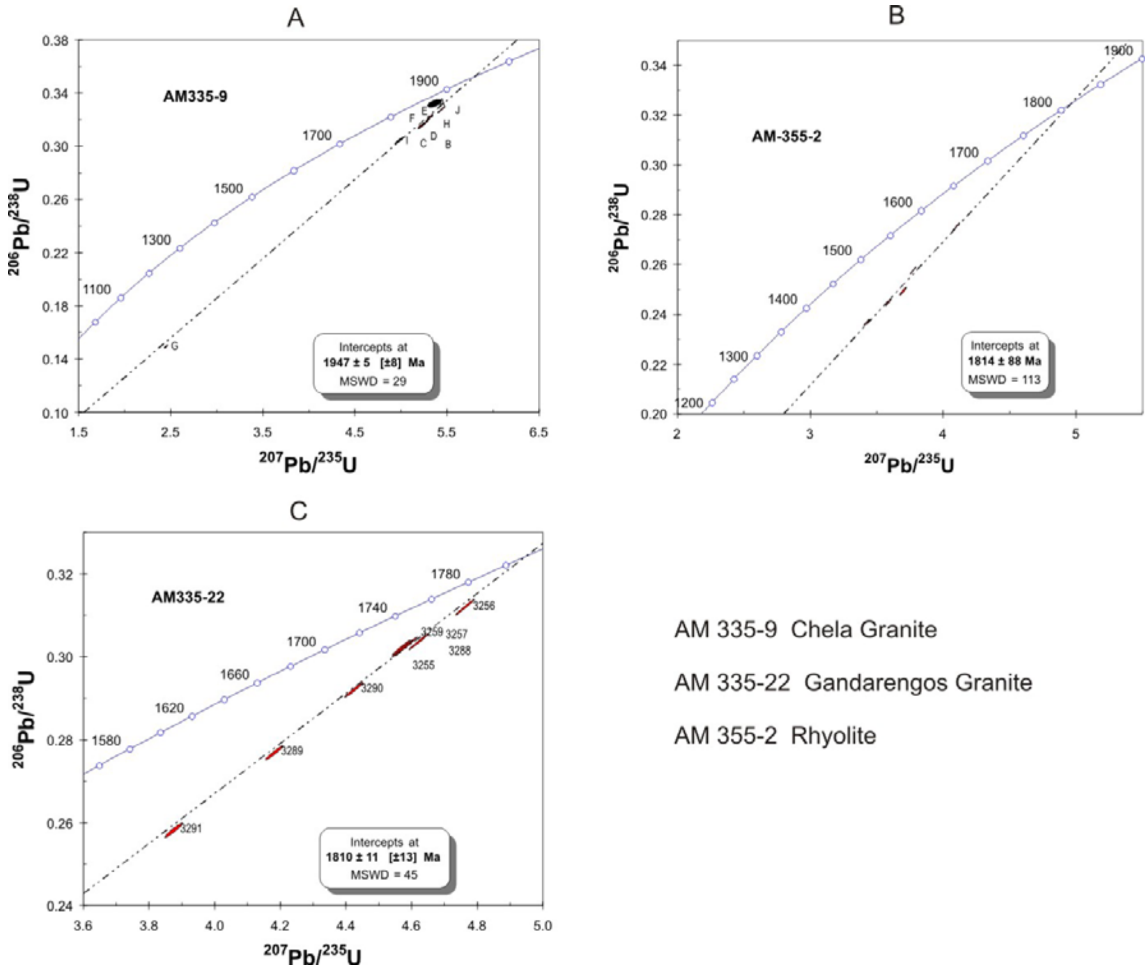

Fig. 6. (A) U-Pb concordia diagram showing zircon results from Chela post-tectonic granitoid. (B) U-Pb concordia diagram showing zircon results from rhyolite intrusive into the Tundavala Formation of the Chela Group. (C) U-Pb concordia diagram showing zircon results from the Gandarengos post-tectonic porphyritic granitoid.

Fig. 6. (A) Diagrama de concórdia U-Pb mostrando resultados sobre zircões do granito pós-tectónica da Chela. (B) Diagrama de concórdia U-Pb mostrando resultados sobre zircões de riolito intrusivo na Formação Tundavala do Grupo Chela (C) Diagrama de concórdia U-Pb mostrando resultados sobre zircões do granito porfiróide pós-tectónico de Gandarengos.

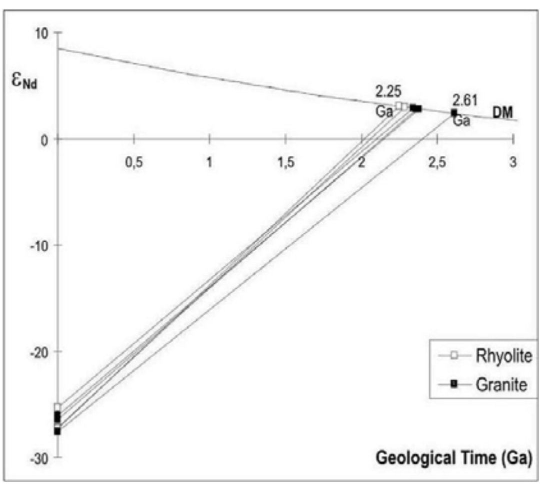

Fig. 7. Similar Nd isotopic composition of the source for the porphyritic granitoids and associated rhyolites with εNd values calculated to 1.8 Ga.

Fig. 7. Semelhante composição isotópica Nd da origem, para os pórfios granitóides e riolitos associados, com valores εNd calculados para 1.8 Ga.

Table 4. Lithotypes, ages and geographic coordinates of all analysed rocks from Bibala –Lubango region, SW of Angola.

Tabela 4. Litótipos, idades e coordenadas geográficas de todas as rochas analisadas da região de Lubango-Bibala, SW de Angola.

Table IV			**Geographic coordinates**	
Sample	**Lithotype**	**Lithotype / Age**	**Latitude (S)**	**Longitude (E)**
335-3	Biotite granite	Similar to 335-22	14 56´ 07´´	13 20´ 15´´
335-8	Foliated granite	≈ 2.1±0.1 Ga Rb/Sr (Torquato et al., 1979).	14 50´ 08´´	13 28´ 47´´
335-9	Coarse biotite granite	1947±5 Ma (U-Pb)	14 43´05´´	13 28´ 04´´
335-11	Migmatitic granite	-----	14 40´ 49´´	13 18´ 55´´
335-16	Granite porphyrie	Similar to 355-2 (?)	14 51´ 15´´	13 08´ 20´´
335-20	Granite porphyrie	Similar to 355-2 (?)	14 37´ 50´´	13 08´ 40´´
335-22	Hornblende granite	1810±11 Ma (U-Pb)	14 50´ 55´´	13 10´ 45´´
355-1	Rhyolite	Similar to 355-2	15 03´ 23´´	13 13´ 72´´
355-2	Rhyolite	1814±88 Ma (U-Pb)	15 03´ 74´´	13 13´ 93´´
355-21	Rhyolite	Similar to 355-2	15 04´ 08´´	13 14´ 03´´
356-2	Granite porphyrie	Similar to 355-2 (?)	15 06´ 40´´	13 40´ 31´´
356-3	Granite porphyrie	Similar to 355-2 (?)	15 08´34´´	13 41´ 59´´

The samples from the rhyolite yielded a Sm-Nd mantle-depleted model ages of 2.2 and 2.3 Ga, with εNd values of -3.3 and -2.8, calculated to 1.8 Ga and the porphyritic granitoid of Gandarengos Mountain yielded a similar Sm-Nd mantle depleted model age of 2.3 to 2.4 Ga and εNd values of -4.1, calculated to 1.8 Ga (Fig. 7). The Sm-Nd data indicates similar Nd isotopic composition for both the rhyolite and the porphyritic granitoid, suggesting the same crustal sources with the presence of an older early Paleoproterozoic crustal component within their magma sources.

6. Discussion of isotopic data

In SW Angola, the basement rocks of the volcano-sedimentary sequence of the Chela Group consist of syntectonic Eburnean granites (two mica foliated granitoids) and late-tectonic Eburnean granitoids (Chela Granite and Gandarengos Granite). In relation to the former ones, characterized by several kinds of lithotypes, an age within the time interval 2100 ± 100 Ma is considered, (Torquato *et al.*, 1979). In addition, the late-tectonic Chela Granite, which also comprises the basement rocks of Chela Group, yielded a zircon U-Pb age of 1947 ± 5 Ma (Fig. 6A). Those isotopic results define very well the timing of the magmatic activities related to Eburnean tectonic evolution, which constitute the maximum age for the Chela Group deposition, within the studied area.

The Gandarengos porphyritic granite, associated with acid volcanism intrusive into the Tundavala Formation provided an U-Pb zircon age around 1810 Ma (Fig. 6C). Our U-Pb zircon age around 1810-1814 Ma obtained from volcano-plutonism intrusive in the Chela Group is coeval with part of this volcano-sedimentary sequence and defines the minimum age for the deposition of the Humpata Formation. The time interval between 1.95 and 1.81 Ga is the main period for the deposition of the Chela Group in this area. Independent of this work, a brief sampling carried out by McCourt *et al.* (2004) from an ignimbrite layer of the volcanoclastic Humpata Formation and from a quartzarenite of the Bruco Formation revealed zircon U-Pb ages ranging from 1765 ± 18 Ma to 2014 ± 12 Ma, respectively, with the largest group of ages clustering around 1990 Ma.

Other granitic bodies, from several areas of the SW of Angola, yielded younger Rb-Sr isochronic ages, such as leucocratic granites and granitoid stocks free of tectonic deformation, both with Rb/Sr age between 1761-1552 Ma. For example, for the acid magmatism of the Caraculo-Bibala region, Carvalho & Tassinari (1992) recognized the following limits: 1750-1700 Ma ($^{87}Sr/^{86}Sr_i$ = 0.706) for the granites from northern Gandarengos and Chonga Mountains and 1550-1500 Ma ($^{87}Sr/^{86}Sr_i$ = 0.705) for the granites from Caraculo-Chicate-Munhino. This magmatic episode mainly of crustal origin ($^{87}Sr/^{86}Sr_i$ = 0.705-0,706) seems to have a regional significance after the deposition of the Chela Group. As mentioned before, it was initially defined by Torquato (1974b) as "Thermotectonic Namibe Event".

7. Geodynamic interpretation

The SW of Angola includes the southern margin of the Congo Craton comprising successive accretions of the pre-Eburnean, Eburnean-Rhyacian, Grenville-Kibaran and Pan-African orogenic belts, ranging from the Archean to the Neoproterozoic-early Paleozoic. Therefore, the geology of the SW of Angola is critical, not only for the understanding of syn and post-Eburnean crustal evolution, but also for the recycling processes that generated the economic resources.

The earliest event observed in the south of the Angolan territory is an Archean crustal remnant that possibly postdates the charnockitization episode of the Congo Craton with around ≤2.8 - ≥2.5 Ga. These basement inliers are composed of gneisses, migmatites, scarce granitoids and perhaps a significant metasedimentary sequence known as the Schist-quartzitic-amphibolitic Complex, which includes marble layers. In areas not affected by the tectonometamorphic Eburnean episode, the structural trend of gneisses and migmatites and also of that metasedimentary Complex is mostly WNW-ESE. This episode and the following Paleoproterozoic period are characterized by an accelerated production of sialic crust, giving rise to the formation of supercontinents (Ernst, 2009).

A possible model for starting the Eburnean-Rhyacian cycle will be the crustal stretching, ascend and underplate setting of mantle that will have induced rifting of a Neoarchean continental crust. The rise and setting of the upper mantle melt can explain the source of wide bodies of amphibolite rocks layered within metasedimentary Eburnean sequences. The anomalous geothermal gradient resulting from the mantle activity may be responsible for the later reworking of the pre-Eburnean basement, the genesis of a large amount of migmatites associated with Eburnean peraluminous granites and a minor amount of late-tectonic metaluminous granitoids. A subsequent collision model can be interpreted on the basis of an "A-type subduction" as defined by Kröner (1983) and Shackleton (1986), and ensuing tectonic implications for the Eburnean Orogeny (2.1-1.8 Ga).

The underplate upper mantle melt and its subsequent fractionation, crustal contamination and continuous extraction would be a plausible explanation for the proliferation of mafic magmatic activity in the SW of Angola. They correspond to the early intrusion of the dioritic and Gabbroic Complex (GC), the subsequent installation of the main body of KIC (Mayer *et al.*, 2004; McCourt *et al.*, 2004; Drüppel *et al.*, 2000; 2007) and the colossal dike swarm and sills of dolerites, subophitic gabbros and noritic gabbros, the major geological feature of the SW of Angola. Thus, the emplacement of large bimodal magmatic bodies in the basement, via multiple intrusions, requires a significant geothermal increase at the margin of the Congo Craton and a prolonged extensional episode. This means that between the "Thermotectonic Namibe Event" and the Pan-African orogeny we are not able to identify, in the studied region, any tectonomethamorphic episode that can be attributed to the Kibaran belt (1300-1000 Ma). The only sedimentary succession susceptible to be affected by this orogeny must be the Chela Group, but this sedimentary sequence does not reveal significant deformation or metamorphism.

The long lasting thermal anomaly registered at the southern margin of the Congo Craton is compatible with continental rifting, development of a triple junction between the Congo, the Kalahary and the Rio de la Plata cratons, as well as, the deposition of the Damara Supergroup. The Neoproterozoic-early Palaeozoic Kaoko belt is very well exposed in the NW of Namibia and extends into the SW corner of Angola. Unfortunately, as we have already said, it is scarcely known in the Angolan geology.

8. Conclusions

From our interpretation, the GC and the KIC are two distinct ultramafic-mafic bodies since the Chela Group, deposited in the interval 1947-1810 Ma, unconformably overlies the GC in the Macota region (Carvalho & Alves, 1990).

After the emplacement of the late-tectonic Chela granite (1947 ± 5 Ma) or Gandarengos granite (1810 ± 11 Ma) and the GC, the region was followed by: i) extensive faulting and deposition of the volcano-sedimentary sequence of the Chela Group coeval with the intrusion of granite porphyries and rhyolites; ii) development of the "Thermotectonic Namibe Event" and installation of several crustal granitoids with Rb/Sr ages between 1761-1552 Ma; iii) emplacement of the KIC, post-dated by a mangerite vein with U-Pb zircon age of 1371 ± 2 Ma (Mayer *et al.*, 2004), and also by U-Pb SHRIMP age of 1385 ± 7.6 Ma (McCourt *et al.*, 2004); iv) later intrusion along the NE-SW fault system, of the A-type granites, syenites and related subvolcanic rocks with around 1400-1300 Ma (Torquato *et al.*, 1979; Bassot *et al.*, 1981; Silva & Simões, 1982; Carvalho *et al.*, 1987); v) and, finally, the successive ascent of mafic rocks around 1.2-1.1 Ga, along brittle faults of various orientations: WNW-ESE, N-S and NNW-SSE systems, compatible with Eburnean stretching.

The NE-SW system that lodges the A-Type granites and syenites and the WNW-ESE system, in which the subophitic gabbros and some dolerites are installed, are extensional transcurrent faults compatible with the ENE-WSW structural trend of the Grenville-Kibaran belt of Namibia, which was not identified in the SW Angolan territory.

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